



# *Network Science and Crowd Behavior Metrics*

## Target Behavioral Response Laboratory

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# The Problem

- Large numbers
- Heterogeneous
- Individual Actors
- Interdependence
- Language Barriers



- Empirical testing is difficult
- Social behavioral research has been lacking
- Simulations require models based on real data, otherwise they are fiction.



# Method



Gather empirical data on  
real people and real  
groups in tactically  
relevant situations

- Groups of 12 individuals
- Controlled motivations toward goal & away from control force with money
- Manipulated type of weapon, size of control force and the ROE.
- Two tactical constructs
  - Approach / Keep away
  - Occupy / Go Away
- Recorded spatial data
- Video recording



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# Test Setup



13-Feb-15

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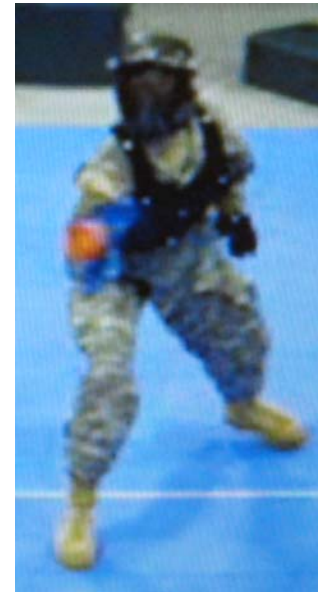




# Data Measurement



- Vicon V8i system
- 24 cameras
- 120 fps
- Optical tracking of retro reflective markers ( $\varnothing 14\text{mm}$ )
- Marker error  $< 10\text{mm}$
- Subjects
  - Unique Helmets
  - XYZ location + 3DOF orientation of head
- Control Force
  - Head & Torso
  - Capability for weapon

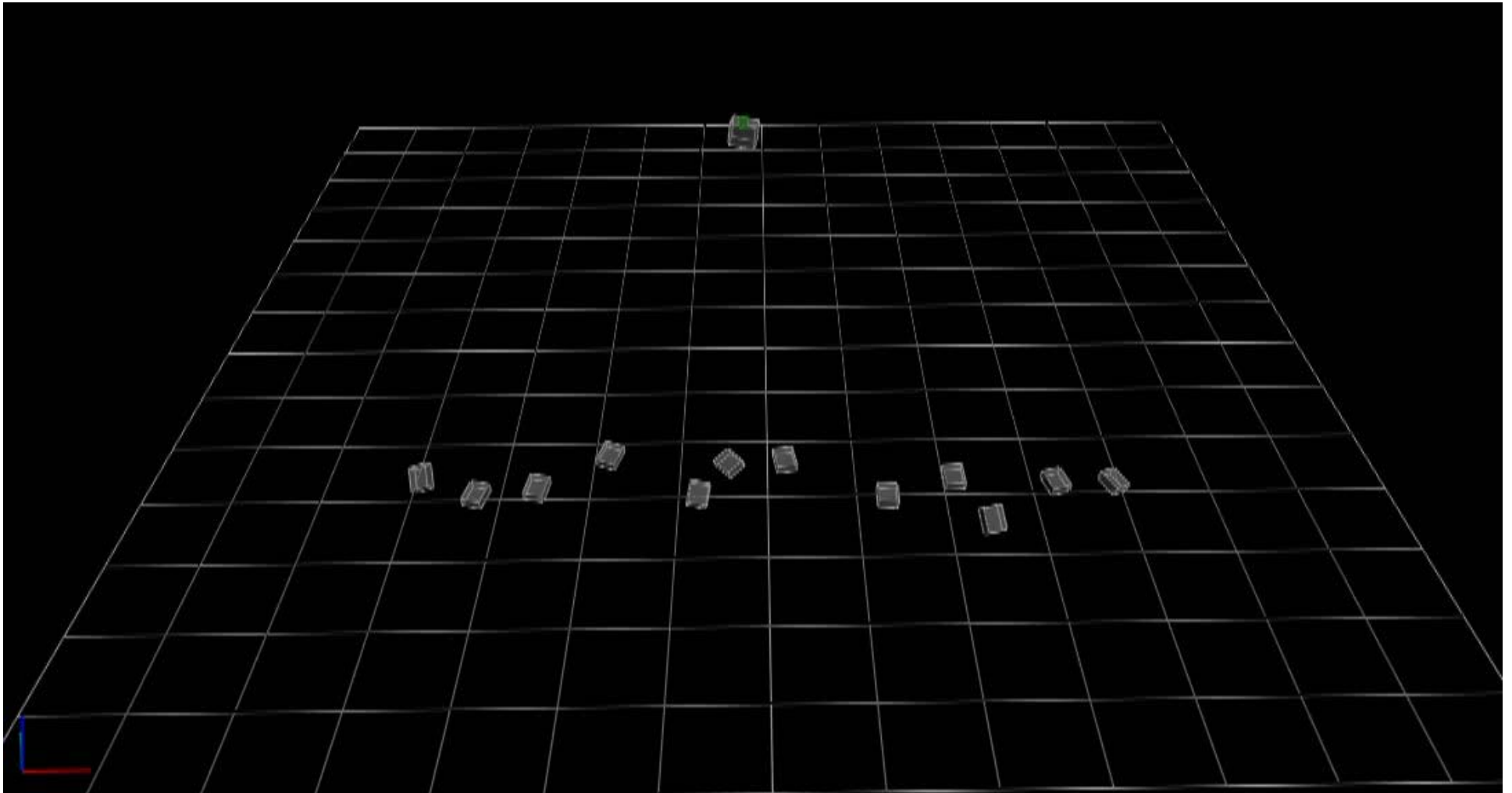


Courtesy Vicon





# Example





# Individual Metrics



$S_{t,Sa}$	Distance covered in interval
$V_{t,Sa}$	Instantaneous Velocity
$ID_{t,Sa,Sb}$	Interpersonal Distance between any pair of subjects
$CD_{t,c,Sa}$	Distance between control force-subject pairs
$CID_{t,c,c}$	Interpersonal Distance between any pair of control force

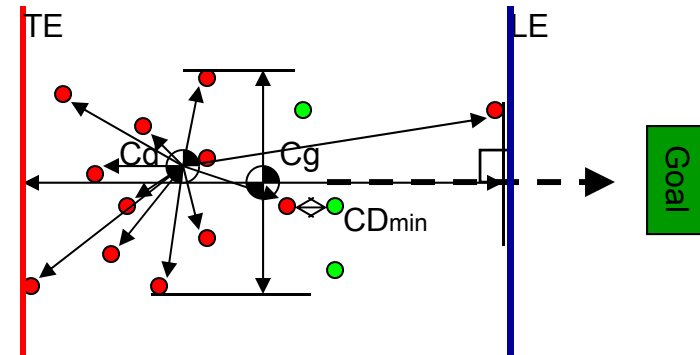


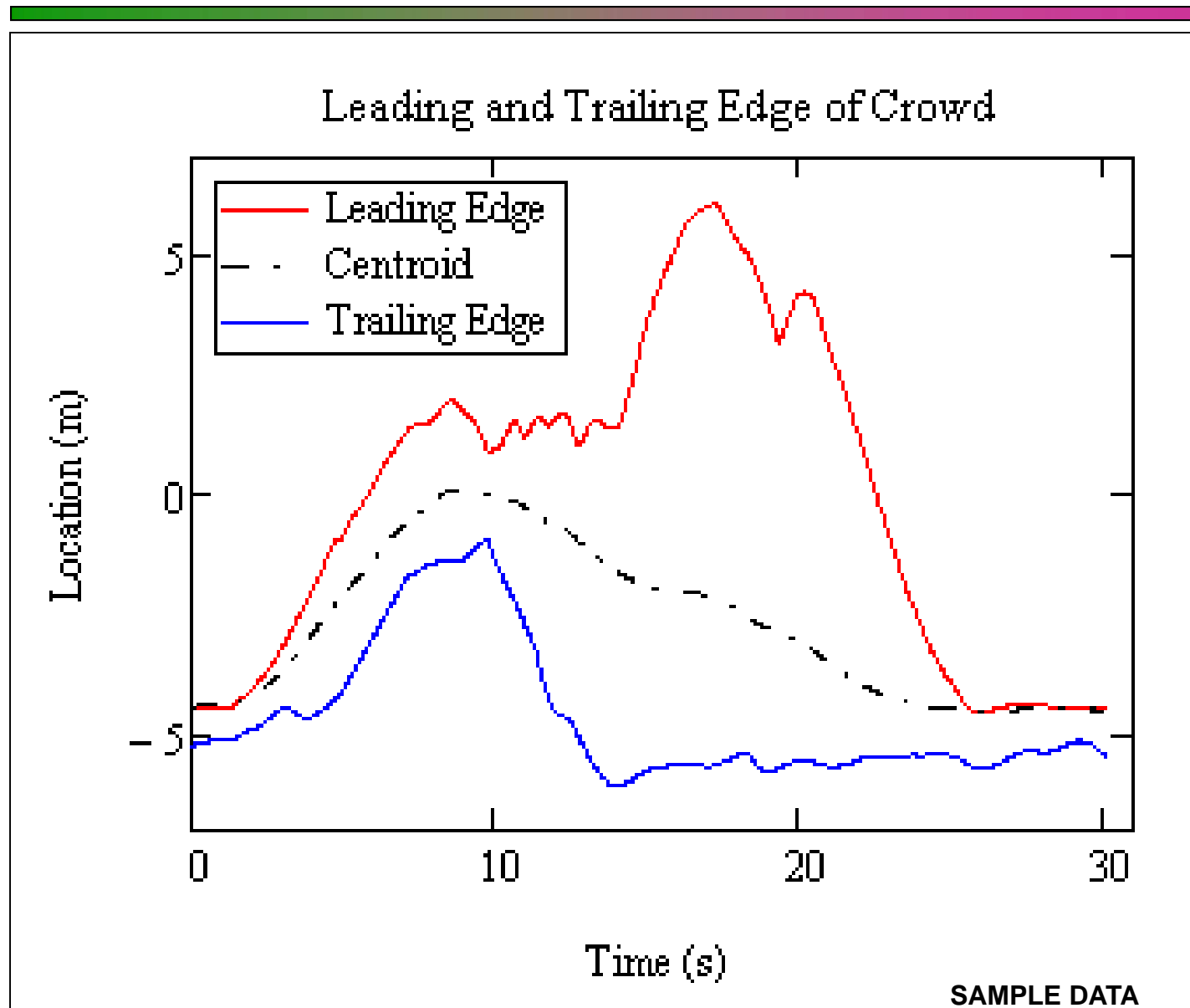


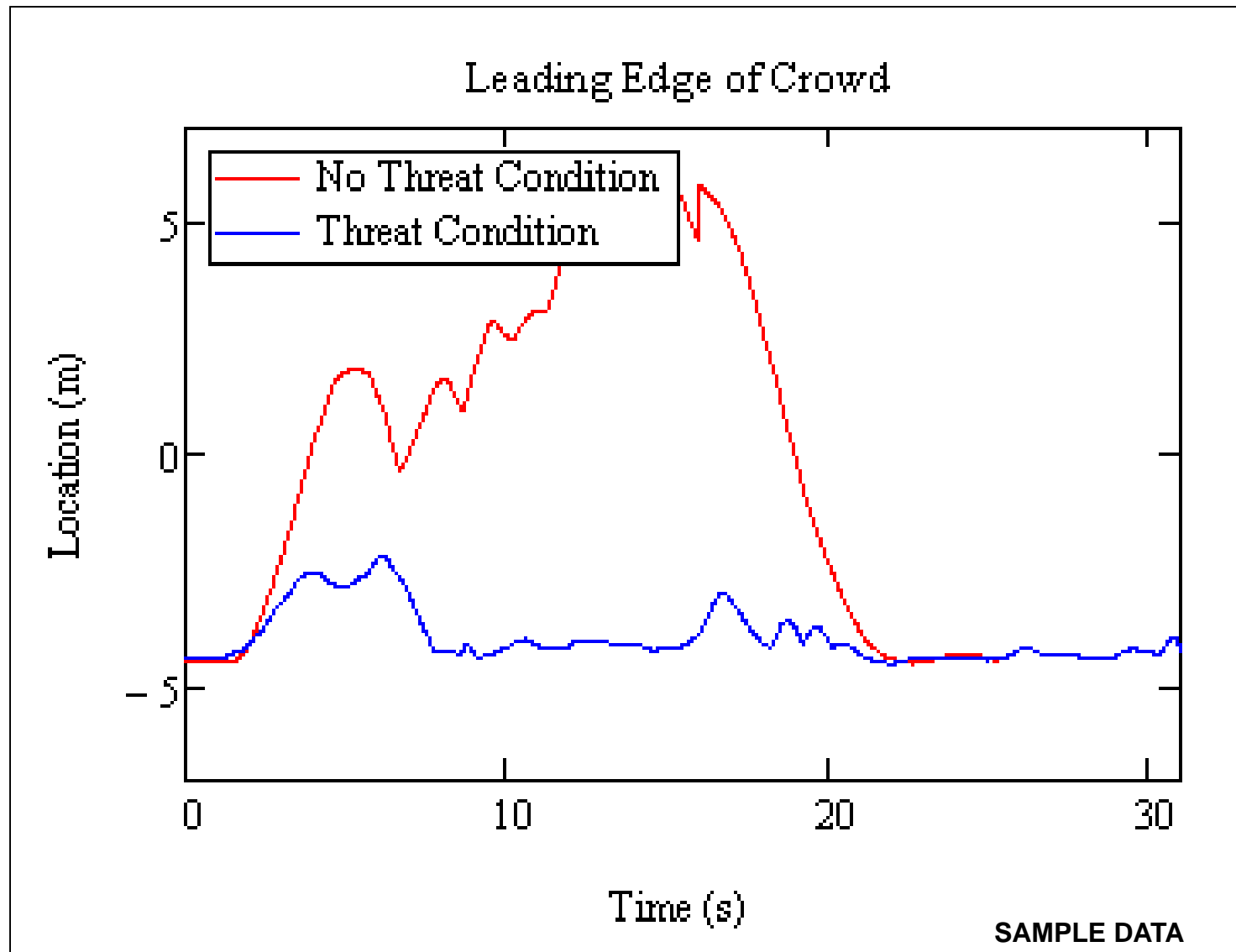
# Crowd Metrics

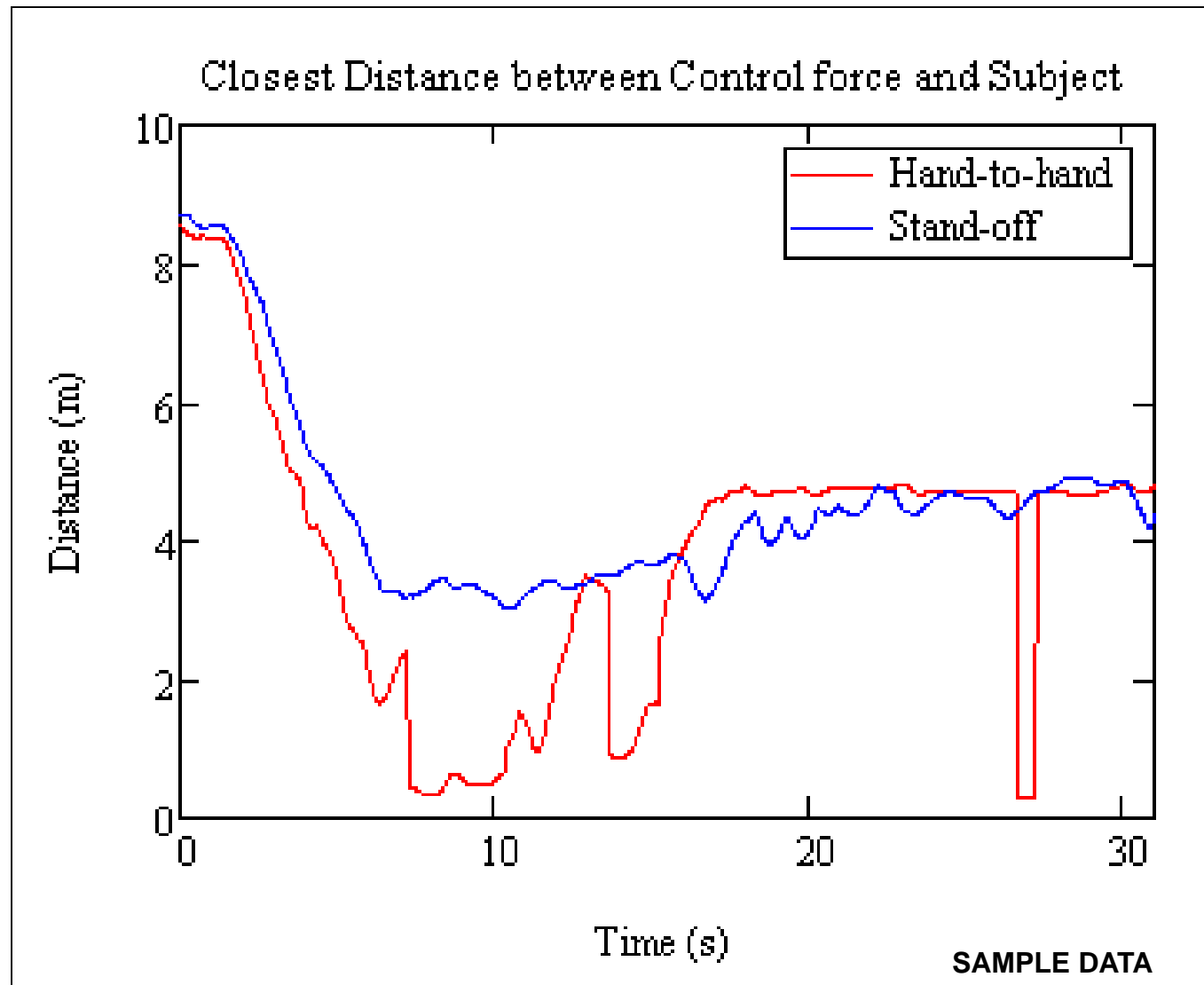
$Cg_t$	Geometric Center- middle of extrema
$Cd_t$	Centroid- mean of subject positions
$D_t$	Dispersion- mean subject radii from centroid
$LE_t TE_t$	Leading/Trailing edge- max/min along the approach axis
$\rho_t$	Density- $\rho_t = N / \pi D_t^2$
$CDmin_t$	Minimum distance between any subject-control force pair
$\sigma O_t \sigma V_t$	Deviation of Orientation/Velocity- StDev of all subjects head orientation or velocity
$Vc_t$	Bulk velocity of crowd- rate of change of centroid

Defined time periods based on events dependent on the construct or scenario used.











# Outcome

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- Probability Distributions
  - Identify the distribution & parameters
  - To be used in Stochastic models of both the aggregate (crowd) level or at the individual level
- Regression Equation
  - $y = (\beta_1 x_1) + (\beta_2 x_2) + (\beta_3 x_3) + \dots + (\beta_{12} x_1 x_2) + \dots + \varepsilon$
  - Identify covariates (interacting & confounding)
  - Determine distributions for coefficients to use in stochastic models
  - Determine coefficients to use in deterministic models



# Social Network Analyses

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- Videotapes coded for pairwise social interaction among crowd members
  - Verbal communication, physical contact, gestures, non-verbal auditory signaling
  - 30-sec epochs at beginning and end for two groups
- 12 x 12 matrix submitted to networking analysis software (ORA Version 1.9.5.2.9)
- Sociometric Data outputted
  - #subgroups, isolates, linkages among nodes





# Adjacency Matrix

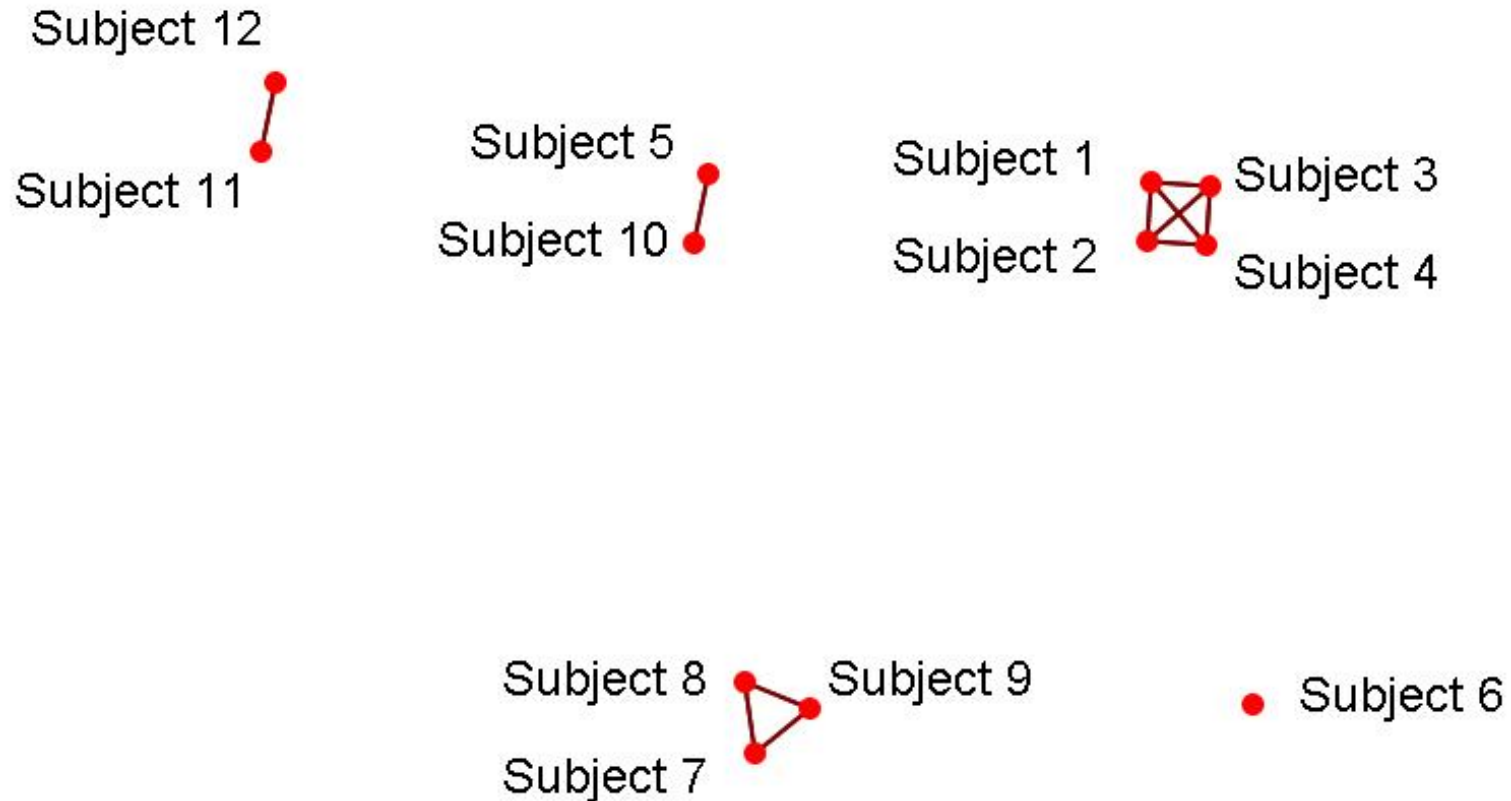


## Intercommunications among Crowd Members

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10	Subject 11	Subject 12
2	Subject 1		1	1	1	0	0	0	0	0	0	0	0
3	Subject 2	1		1	1	0	0	0	0	0	0	0	0
4	Subject 3	1	1		1	0	0	0	0	0	0	0	0
5	Subject 4	1	1	1		0	0	0	0	0	0	0	0
6	Subject 5	0	0	0	0		0	0	0	0	1	0	0
7	Subject 6	0	0	0	0	0		0	0	0	0	0	0
8	Subject 7	0	0	0	0	0	0		1	1	0	0	0
9	Subject 8	0	0	0	0	0	0	1		1	0	0	0
10	Subject 9	0	0	0	0	0	0	1	1		0	0	0
11	Subject 10	0	0	0	0	1	0	0	0	0		0	0
12	Subject 11	0	0	0	0	0	0	0	0	0	0		1
13	Subject 12	0	0	0	0	0	0	0	0	0	0	1	

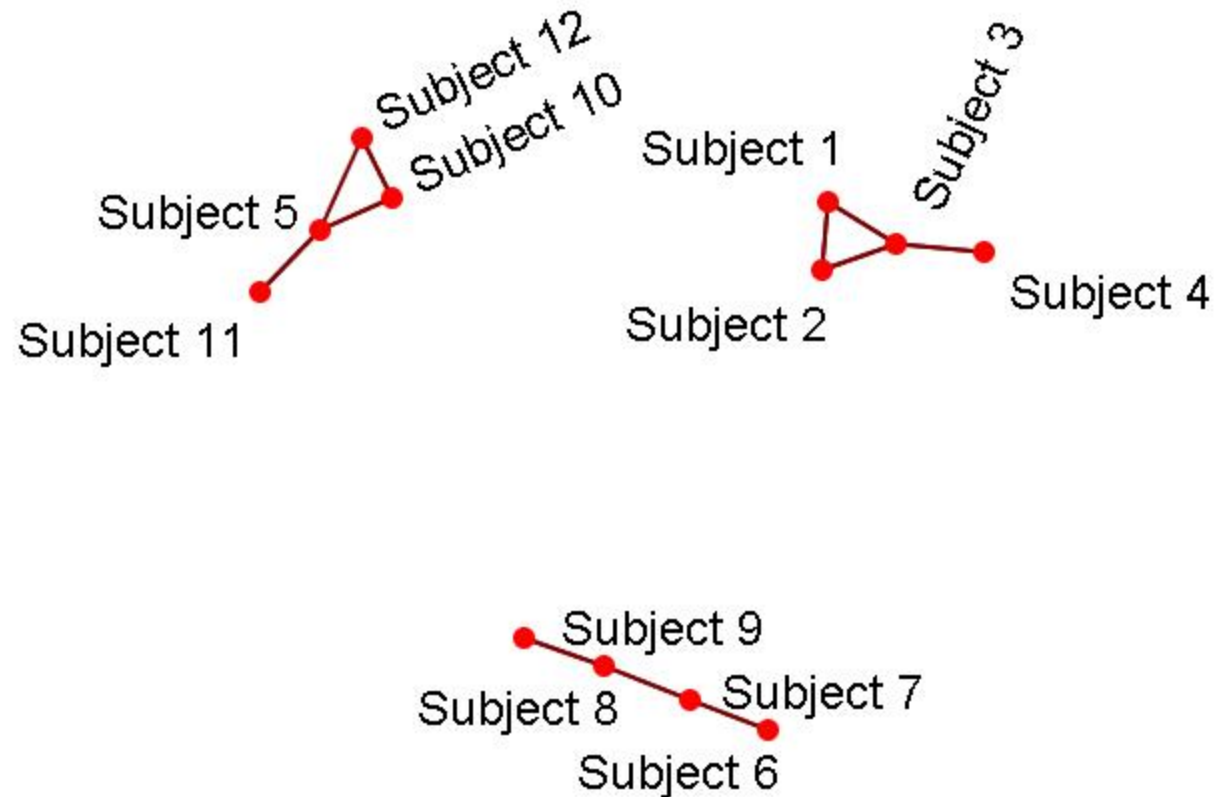


# *TBRL* → Crowd A at Beginning of Experiment



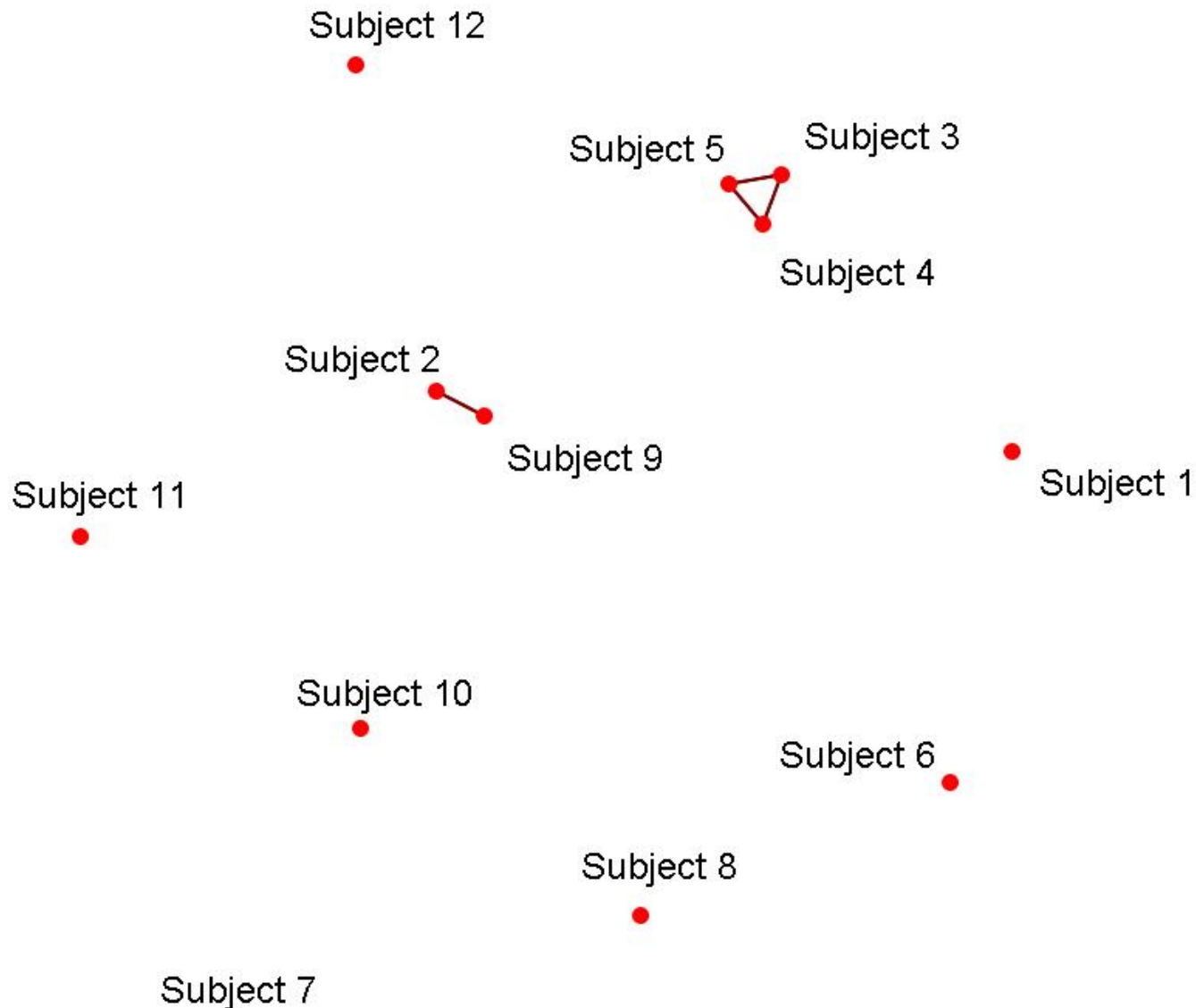


# Crowd A at End of Experiment



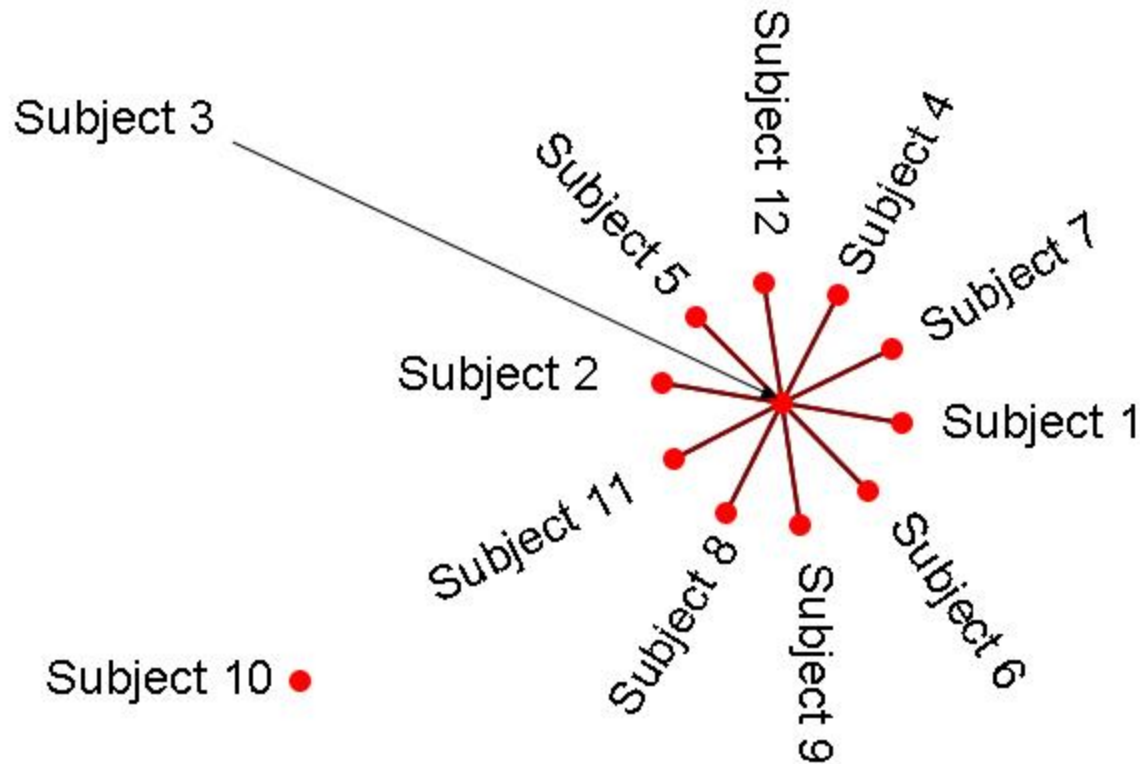


# Crowd B at Beginning of Experiment





# Crowd B at End of Experiment





# Results

## Crowd Level Sociometrics

<i>Variable</i>	<i>CROWD A</i>		<i>CROWD B</i>	
	Beginning	End	Beginning	End
Node Count	12	12	12	12
Link Count	22	21	8	20
Number of Subgroups	4	4	2	1
Number of Quads	1	4	0	0
Number of Triads	1	0	1	0
Number of Dyads	2	0	1	0
Number of Isolates	1	0	7	1
Density	0.1667	0.1591	0.0600	0.1515

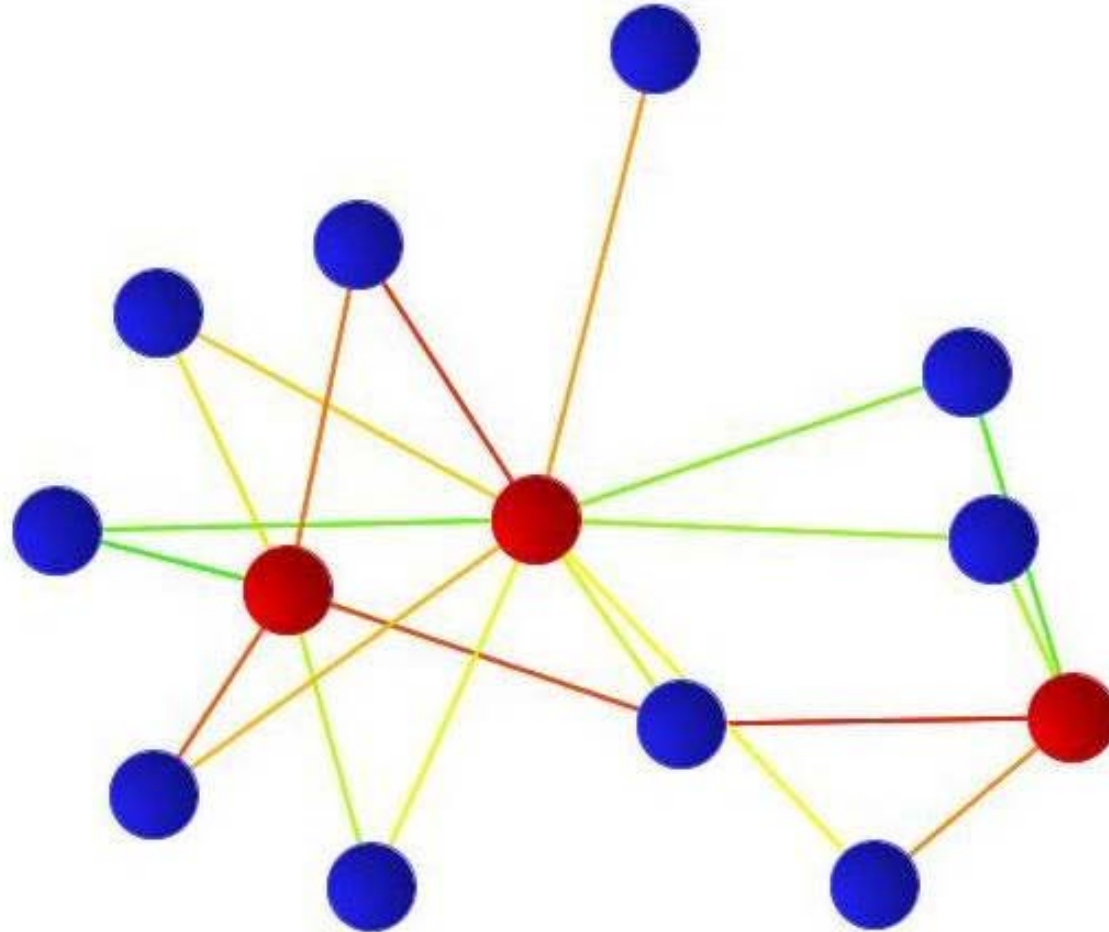




# Network Analysis

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## Control Force – Crowd Member Distances





# Conclusion

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## Crowd Behavior Metrics

- Empirical data collected and analyzed under controlled laboratory conditions
- Motion capture analyses yield quantitative methods for analyses of crowd responses
- Network analyses yield quantitative methods for crowd psychosocial characterization
- Both individual and crowd level analyses



# The Way Forward

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- With the development of crowd measures and metrics and wide variety of applied, practical, and tactically relevant questions can be explored
- Target selection
- Threat assessment
- Input into modeling and simulation investigations
- Comparisons of effectiveness of a variety of non-lethal weapons and systems and tactics, techniques, and procedures



# Backup Slides



# Theoretical Model

## Mechanisms of Non-Lethal System Effects on Crowd Members

